Hydrodynamics and the Morphology of Nebulae

Extragalactic nebulae, in the first approximation, may be regarded as gravitating continuous "viscous fluids," most of them endowed with total angular momenta different from zero.[1] In every nebula two coexisting partial systems must be considered: (1) a *stellar system* and (2) a system formed by *interstellar gases* and dust particles. Hydrodynamically, the two partial systems have radically different characteristics inasmuch as the gaseous systems are characterized by much larger *Reynolds numbers* than the stellar systems. In most cases the motions of the gaseous systems will be turbulent. The Reynolds numbers of the stellar systems lie in the approximate range $0<R<10{,}000$. The flow of stars in some nebulae therefore is "*laminar*," whereas in others it may be "*turbulent*." Nebulae in which the two types of flow coexist show interesting structural subdivisions.

Briefly, some of the results of the hydrodynamical analysis of nebulae are as follows. In an undisturbed nebula of constant total angular momentum, the viscous shearing stresses tend to make the average angular velocity $\bar{\omega}(r)$ independent of the distance r from the center as long as r is smaller than that critical distance r_s at which the mean free path Λ of the particles (or stars) is so great that the difference in gravitational potential $\Phi(r_s+\Lambda)-\Phi(r_s)$ becomes comparable with $\langle w^2\rangle_{\mathrm{Av}}$, where w is the velocity of the particles. For $r>r_s$ the angular momenta of the individual particles, rather than $\bar{\omega}$, tend to be constant. In a rotating nebula which has reached a stationary state the average velocity distribution $\bar{v}(r)$ is of the type shown in Fig. 1. Calculations based on the actions of shearing stresses in a laminar flow show that the relaxation time T which is needed to establish the solid body rotation is of the order $Rr_s/\bar{v}_{\max}$ if the original motion deviates from the state $\bar{\omega}=$const. by maximum velocity differences $\bar{v}_{\max}$. For an originally turbulent flow, it is $T\ll Rr_s/\bar{v}_{\max}$. The interstellar gas system therefore reaches the state $\bar{\omega}=$const. long before the stellar system.

In the transition stages of a *stellar system* from $\bar{\omega}\neq$const. to $\bar{\omega}=$const. velocity distributions of the type shown in Fig. 2 may be expected. Region I was originally *turbulent* with large shearing stresses which make T small. Region IIa is characterized by smaller values of R and the smaller shearing stresses of the resulting *laminar* flow result in relatively large values of the time T in which a distribution $\bar{\omega}=$const. can be achieved. Region IIb, because of still smaller R, is a *laminar* flow subject to small values of T. Regions I and IIb consequently reach the stationary state $\bar{\omega}=$const. earlier than the region IIa. While the transition from I to IIa is abrupt, the transitions from IIa to IIb and from IIb to III are more gradual. Region III may be called the *Smoluchowski region* of very long mean free paths. The existence of such regions (globular coronae around nebulae!) is due to effects analogous to those which cause Smoluckowski "temperature jumps" and "slip regions" in ordinary dilute gases.

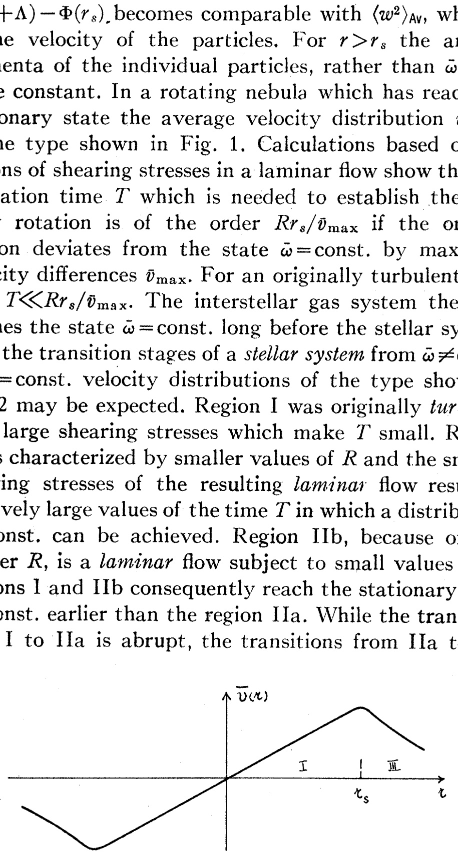

FIG. 1. Velocity distribution in the transition stage of a rotating nebula. The constant angular velocity in the region I and IIb.

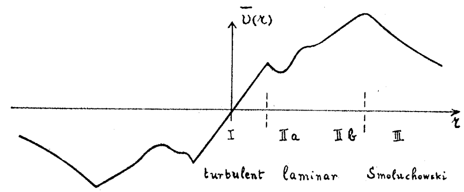

FIG. 2. Velocity distribution in the transition stage of a rotating nebula. The constant angular velocity in the regions I and IIb and the character of $\bar{v}(r)$ in region IIa depend on the original distribution of velocities.

The existence of turbulent motions in stellar systems leads to interesting speculations regarding the *turbulent correlation length L*. The properties of the *planetary system* as well as of *groups of stars* which are dynamically related may find their explanation in the analysis of this correlation length.

Nebulae of *small mass* may possess a Smoluchowski structure throughout. These nebulae never can reach a Boltzmann stationary state. They are *irregular*, of low surface brightness and hard to detect. Recent systematic search has resulted in the discovery of several systems of this type. Their incorporation in the statistical survey suggests that the frequency distribution of nebulae commonly adopted will in the near future be subject to some major corrections.

Hydrodynamic considerations may also be applied to *clusters of nebulae*. The important fact, which is apparently irreconcilable with the hypothesis of an expanding universe,[2] that the velocity dispersion of field nebulae is only about half that for cluster nebulae, finds its explanation through an analysis similar to that sketched in this communication.

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[1] F. Zwicky, Astrophys. J. **86**, 217 (1937).
[2] F. Zwicky, Proc. Nat. Acad. Sci. **25**, 604 (1939); **26**, 332 (1940).

Protons from $C^{13}+H^2$

Bower and Burcham[1] and also Pollard[2] have observed a group of protons which they attributed to the reaction $C^{13}+H^2\rightarrow C^{14}+H^1+Q$. Bower and Burcham found a 48-cm group of protons when ordinary carbon was bombarded by 800-kev deuterons. The calculated Q value of this group is 5.9 Mev, which is in satisfactory agreement with the energy release calculated from the change in mass. We have confirmed that the proton group must be attributed to the above reaction by using a target of concentrated C^{13}. The target was prepared by one of us (BEW) from methane in which the C^{13} had been concentrated by thermal diffusion.